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Control, coordination and conflict on international commodity markets

Willem van Groenendaal and Aart de Zeeuw

The effects of price stabilization policies have been investigated for both theoretical and empirical models. The institutional construct for international commodity markets is that a buffer stock manager employs a band width rule or a price adjustment rule to stabilize the world market price. In those investigations it is assumed that the other market participants do not react to the stabilization activities of the buffer stock manager. This paper describes an international commodity market as a difference game between buffer stock manager, producing countries and consuming countries and uses an empirical model for the world cocoa market to analyse the effects. The feedback Nash behavioural equilibrium for this game is compared with the optimal control outcome which ignores the strategic behaviour in producing countries and consuming countries. It is found that producers and consumers engage in storage activities which have a negative effect on the stabilization efforts of the buffer stock manager but which decrease the operating costs of the buffer stock, decrease the revenues of the producers and decrease the costs of consumers.

Keywords: Buffer stock price stabilization; International cocoa market; Optimal control; Difference games

International commodity agreements which aim for price and revenue stabilization are a major policy issue at meetings of UNCTAD. Especially during the last conferences the main if not only objective formulated in the agreements has been price stabilization around a long-term trend (see eg UNCTAD [22]). The desirability of price stabilization has been an important theoretical issue in the economic literature for a long time. Turnovsky [21] surveys and extends the Waugh-Oi-Massell analysis. Prices are random because of stochastic fluctuations in demand and supply. The criteria for judging the desirability of price stabilization are the expected producers' surplus and the expected consumers' surplus. The main conclusion of the Waugh-Oi-Massell-Turnovsky analysis is that the source of the fluctuations determines whether the surplus improves or deteriorates. In general the sum of the surpluses ie total welfare improves. Newbery and Stiglitz [17] argue that the market is in fact competitive and complete because future and risk markets are redundant. This implies that the market equilibrium is Pareto efficient, so that the optimal stabilizing policy is to reproduce the storage decisions of risk neutral competitive speculators with rational price forecasts. Turnovsky [21] and Newbery and Stiglitz [17] emphasize that perfect price stability is either not feasible or infinitely costly. It is better to analyse partial adjustment policies or the optimal degree of price stabilization.

In the literature two types of stabilization policies are distinguished. The first is a band width rule, which means that the stabilizing agency intervenes when the price moves above or below an *a priori* specified price band. This is the sort of rule that is suggested in international commodity agreements and it is referred to by Newbery and Stiglitz [17] as the pragmatic

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approach. The second is a price adjustment rule which means that the stabilizing agency is constantly trying to keep the price as close as possible to an *a priori* specified target price path. This is the sort of rule that also results from an optimal control approach to the stabilization problem.

Lee and Blandford [16] use empirical models for the world cocoa and copper markets and perform an optimal control analysis for price and revenue stabilization. They stress the need to take account of the systematic trend of the price in setting the target price path because otherwise the attempts to stabilize are doomed to fail. Their conclusion is that it is likely to require substantial market intervention to produce a significant reduction in price instability, although price stability can have a favourable impact on the level and stability of producers' revenues. Ghosh, Gilbert and Hughes Hallett [10] construct a model of the world copper market in which the market clearing identity is replaced with an explicit price formation mechanism. They compare band width rules with optimal control results and conclude that band width rules are no match for optimal stabilization schemes. Hughes Hallett [13] explores the problem further. The conclusion is again that significant stabilization of the copper market is possible but very expensive. However, in contrast with Lee and Blandford [16] there is now no improvement in the level of producers' earnings, although the variability can be reduced substantially. This is in line with the theoretical results that are reported in Turnovsky [21].

Turnovsky [21] and Newbery and Stiglitz [17] raise the question of what the impact of the actions of the stabilizing authority on private speculative storage might be and whether the actions of private speculators might jeopardize the desired outcome. Lee and Blandford [16] and Hughes Hallett [13] also emphasize the assumption in their exercise that the behaviour of market participants is unaffected by buffer stock stabilization. The Lucas critique argues that this assumption is not realistic and might lead to the wrong policy advice. This paper therefore suggests using a difference game approach instead of an optimal control approach. In this way it is possible to study what happens when producers and consumers can also employ storage activities in reaction to buffer stock activities and when the buffer stock manager realizes this. It must be stressed that the Lucas critique is not completely resolved in this way because other behaviour is kept fixed in the model. The storage behaviour of the buffer stock manager, producers and consumers is modelled as an optimal control problem and the strategic interaction is modelled as a game. It is suggested that the feedback Nash or subgame perfect equilibrium concept should be employed in this difference game. An algorithm which leads to this equilibrium is given by de Zeeuw [24]. In this paper an empirical model for the world cocoa market is used which is based on a model developed in van Groenendaal and Vingerhoets [12]. This model consists of estimated equations for production and consumption and for several price indices.

The optimal stabilization policy of the buffer stock manager based on an optimal control approach is compared with the Nash equilibrium between buffer stock manager, producing countries and consuming countries. The idea is that a country modelled as a strategic agent represents all strategic activities within that country. In this Nash equilibrium the producing countries aim for higher export prices and the consuming countries aim for lower import prices. In the attempt to stabilize the world market price the buffer stock manager is restricted by the available buffer stock, which can never become negative. In their attempt to get a better export price or import price the countries are restricted in their storage decisions by assumptions about the reasonable size of the stock. The conclusions are that both producing countries and consuming countries engage in storage activities which counteract the stabilizing efforts of the buffer stock manager, although this effect is small. The buffer stock can be successful in stabilizing world market prices and revenues but there remains a conflict on the market which calls for further coordination. It is interesting that the operating costs of the buffer stock decrease in the game setting. In addition, when producing countries and consuming countries are both active, producers are worse off whereas consumers are better off.

This paper is organized as follows. The next section presents an empirical model for the world cocoa market. The following section gives algorithms for the optimal control solution and the feedback Nash behavioural equilibrium in a linear quadratic framework. The price stabilization problem is then formulated in the next section as an optimal control problem, when there is no speculation, and as a Nash difference game, when there is speculation. The algorithms given in the previous section are applied to the cocoa model presented earlier and the results for the optimal control formulation and the Nash difference game formulation are compared. The last section offers conclusions.

Cocoa model

Cocoa beans are produced in underdeveloped and less developed countries and cocoa products are mainly consumed in developed countries. This implies that the trade between producers and consumers is typically

Table 1. Production.[a]

$$\Delta QR_t = \beta_0 + \sum_{j=0}^{8} \beta_{j+1}(PFI/PC)_{t-j} + \beta_{10}QR_{t-1} + \beta_{11}HY_{t-4} + \beta_{12}t + \beta_{13}DU65$$

Country or region	Cameroon	Ghana	Nigeria	Ivory Coast[b]	Rest of Africa	Brazil	Rest of South America	Asia and Oceania
β_0		170.5		115.0		76.3	143.4	−46.0
t		(4.5)		(5.6)		(2.2)	(3.6)	(−3.4)
β_1	0.36		3.46	2.02				
t	(3.6)		(7.4)	(5.7)				
β_2		1.97		−2.02		0.38	0.14	
t		(3.9)		(0.0)		(2.8)	(2.4)	
β_3		−0.89	1.05					
t		(−1.6)						
β_4			−1.48				0.18	
t							(2.1)	
β_5								
t								
β_6		1.17	−2.82	1.61			0.17	0.05
t		(2.2)	(−6.3)	(5.1)			(2.7)	(1.6)
β_7		−2.18		−1.55				0.06
t		(−3.3)		(−3.6)				
β_8				1.01	0.13		−0.31	
t				(2.4)	(2.1)		(−2.3)	
β_9		0.98	1.89	−1.16				
t		(3.2)	(6.3)	(0.0)				
β_{10}	−0.38	−0.75	−0.90	−0.59	−0.17	−0.57	−0.85	−0.48
t	(−3.3)	(−6.4)	(−8.7)	(−5.1)	(−2.2)	(−2.7)	(−3.7)	(−2.2)
β_{11}		163.2	140.1	−46.8				
t		(4.5)	(4.9)	(−2.1)				
β_{12}				803.5		197.0		
t				(6.0)		(1.4)		
β_{13}								2.52
t								(3.1)
R^2	0.41	0.87	0.86	0.93	0.22	0.45	0.60	0.57

[a] In addition to the variables mentioned in the second section, three other factors were introduced. First, a dummy variable *DU65* for the year 1965, in which year the weather conditions were extremely good. Second, a variable *HY* which represents a change in technology due to the introduction of hybrids. Third, a time trend *t* for Asia and Oceania, which reflects local government policy of increasing the acreage for cocoa trees.

[b] The following restrictions were introduced: $\beta_1 = \beta_2$ and $\beta_9 = \beta_6 + \beta_7 + \beta_8$.

international trade between countries or regions. The structure of the model reflects this observation. The exports and imports of intermediate cocoa products are transformed into cocoa bean equivalents so that cocoa beans are in fact the only traded goods. Suan Tan ([20], pp 71–83) reviews the theory underlying the construction of this type of model. The sampling period is in principle 1960–82 and most of the data originate from FAO *Cocoa Statistics* [6], Gill and Duffus *Cocoa Market Reports* [11] and the ICCO *Quarterly Bulletin* [14].

The producing countries or regions are Cameroon, Ghana, Nigeria, Ivory Coast, the rest of Africa, Brazil, the rest of South America and Asia and Oceania. The production of cocoa beans depends on the area planted and the average production per acre of land. Akiyama and Duncan [2] therefore use equations for acreage and for average production in their model. However, since the data for acreage are not reliable (FAO [9]), here only one equation for production is used. Under fairly reasonable assumptions this is in any case not a severe restriction (Ady [1], Bateman [4]). The decision on a change in production is based on the development (or adaptive expectation) of real producer prices, *PFI/PC*, as an indicator of expected profits. The resulting specification is

$$\Delta QR_t = \beta_0 + \sum_{j=0}^{8} \beta_{j+1}(PFI/PC)_{t-j} + \beta_{10}QR_{t-1} \tag{1}$$

Table 1 gives the estimation results.

The consuming regions are North America, Western Europe, Eastern Europe (including the USSR) and the

Table 2. Consumption.[a]

$$CC/POP_t = \omega_0 + \omega_1(GNPR/POP)_t + \omega_2(PI/PC)_t + \omega_3(PS/PC)_t + \omega_4(CC/POP)_{t-1}$$

Country or region	North America	Western Europe	Eastern Europe	Rest of the world
ω_0		0.70		0.30
t		(4.3)		(2.9)
ω_1	0.10	0.06	2.48	0.08
t	(2.6)	(2.6)	(4.3)	(2.8)
ω_2	−0.17	−0.08	−0.38	−0.11
t	(−2.9)	(−3.2)	(−4.3)	(−2.8)
ω_3	−0.35	−0.13		
t	(−2.55)	(−1.8)		
ω_4	0.78	0.49	0.30	0.51
t	(7.1)	(3.9)	(1.6)	(3.1)
R^2	0.78	0.77	0.78	0.82

[a] For Eastern Europe and the USSR there are no figures on the price of consumption. PI and PS were therefore used instead of relative prices.

rest of the developed world. There is an especially large trade in intermediate cocoa products between North America and Brazil. Imports therefore consist of cocoa beans for grinding as well as powder, paste and butter transformed into cocoa bean equivalents. Cocoa consumption per capita, CC/POP, is based on real gross per capita income, $GNPR/POP$, and on real cocoa prices. The real import price, PI/PC, is used to represent the real cocoa price. The real price of sugar, PS/PC, is introduced to account for possible substitution or complementary products. The resulting specification is

$$(CC/POP)_t = \omega_0 + \omega_1(GNPR/POP)_t + \omega_2(PI/PC)_t + \omega_3(PS/PC)_t + \omega_4(CC/POP)_{t-1} \quad (2)$$

Table 2 gives the estimation results.

The producer prices, PFI, are expressed in home currency and the export prices, PE, in US dollars. Because of government policy and quality differences these prices are not simply related through the exchange rates, RE. For the same reason export prices, PE, and import prices, PI, are not equal to the world market price, $PICCO$. For all these price equations an autoregressive distributed lag model of the first order was introduced. The resulting specifications are

$$PFI_t = \kappa_1 PE_t \times RE_t + \kappa_2 PE_{t-1} \times RE_{t-1} + \kappa_3 PFI_{t-1} \quad (3)$$

$$PE_t = \kappa_1 PICCO_t + \kappa_2 PICCO_{t-1} + \kappa_3 PE_{t-1} \quad (4)$$

$$PI_t = \kappa_1 PICCO_t + \kappa_2 PICCO_{t-1} + \kappa_3 PE_{t-1} \quad (5)$$

Tables 3, 4 and 5 give the estimation results.

The world market cocoa price, $PICCO$, depends on the difference between world supply and demand. Buffer stock operations, ΔBST, have a direct influence on this difference. Supply, $ERWT$, sums up the production per country or region minus a change, ΔST, in stocks, which are held for strategic reasons in that country or region. Demand, $IRWT$, sums up the demand for grindings per region plus the imports of cocoa bean equivalents plus a strategically held change, ΔST, in stocks. Apart from stocks held for strategic reasons it is also assumed that the consuming regions keep a fraction of the demand for grindings in stock for production of cocoa products. This desired level of stocks is set equal to the average level of stocks over the period 1968–80 ($0.225 \times IRWT$). The definitional equation for total demand, $IRWT$, also includes an autonomous component, $CCRR$, to account for imports in countries or regions, which are not modelled explicitly. Differences in world supply and demand will also create changes, $\Delta STWT$, in free stocks of cocoa bean equivalents (the factor 0.99 accounts for transport losses). These free stocks will influence the world market price in so far as they differ from the desired level of stocks. Changing demand will induce a change in the desired level of stocks ($0.225 \times \Delta IRWT$). This will lead to a change in the demand for stocks and therefore this term is added to demand, $IRWT$, in the specification for the world market cocoa price. Since markets are not independent the commodity price index, CPI, is included in the specification in order to separate the effect of differences in supply and demand on the cocoa market from the spill over effects from other markets. Indicators for the instability of monetary variables did not have any significant influence. The relevant definitional equations and the resulting specification for the world market cocoa price are as follows.

World supply

$$ERWT_t = \sum_{j=1}^{8} [QR_{tj} - \Delta ST_{tj}] \quad (6)$$

World demand

$$IRWT_t = \sum_{i=1}^{4} [CC_{ti} + \Delta ST_{ti}] + CCRR_t \quad (7)$$

World stocks

$$STWT_t = STWT_{t-1} + [0.99 \times ERWT_t - IRWT_t - \Delta BST] \quad (8)$$

Table 3. Producer prices.[a]

$PFI_t = \kappa_1 PE_t \times RE_t + \kappa_2 PE_{t-1} \times RE_{t-1} + \kappa_3 PFI_{t-1}$

Country or region	Cameroon	Ghana	Nigeria	Ivory Coast	Rest of Africa	Brazil	Rest of South America	Asia and Oceania
κ_1	0.05	0.18		0.07	0.12	0.74		
t	(1.8)	(5.7)		(1.1)	(2.6)	(20.3)		
κ_2	0.15		0.21	0.16	0.10	−0.45		
t	(3.6)		(2.6)	(2.2)	(1.2)	(−2.4)		
κ_3	0.63	0.63	0.79	0.59	0.65	0.60		
t	(7.7)	(6.6)	(5.1)	(4.4)	(4.0)	(2.1)		
R^2	0.99	0.98	0.98	0.97	0.98	0.99		

[a] For the rest of South America and Asia and Oceania producer prices are not known. It is assumed that for these regions producer prices are equal to export prices in home currency: $PFI = PE \times RE$. For the rest of Africa an index (1975 = 100) was used based on the sum of producer prices in US dollars, weighted by production.

Table 4. Export prices.

$PE_t = \kappa_1 PICCO_t + \kappa_2 PICCO_{t-1} + \kappa_3 PE_{t-1}$

Country or region	Cameroon	Ghana	Nigeria	Ivory Coast	Rest of Africa	Brazil	Rest of South America	Asia and Oceania
κ_1	0.58	0.36	0.72	0.49	0.43	1.08	0.93	0.81
t	(9.6)	(5.4)	(7.0)	(8.5)	(8.4)	(22.0)	(84.5)	(24.6)
κ_2	0.32	0.62		0.38	0.43	−0.12		0.08
t	(5.1)	(9.1)		(6.5)	(8.3)	(−2.4)		(2.5)
κ_3			0.17					
t			(1.4)					
R^2	0.98	0.98	0.92	0.98	0.98	0.99	0.99	0.99

Table 5. Import prices.

$PI_t = \kappa_1 PICCO_t + \kappa_2 PICCO_{t-1} + \kappa_3 PE_{t-1}$

Country or region	North America	Western Europe	Eastern Europe	Rest of the world
κ_1	0.54	0.56	0.54	0.74
t	(11.1)	(14.2)	(8.6)	(15.4)
κ_2	0.51	0.36	0.50	0.32
t	(10.4)	(9.0)	(7.7)	(6.5)
κ_3				
t				
R^2	0.99	0.99	0.99	0.99

World market cocoa price

$$PICCO_t = \alpha_1 CPI_t - \alpha_2 [ERWT_t - (IRWT_t + 0.225 \times \Delta IRWT_t) - \Delta BST_t] - \alpha_3 [STWT_{t-1} - 0.225 \times IRWT_{t-1}] + \alpha_4 PICCO_{t-1} \tag{9}$$

Table 6 gives the estimation results.

Table 6. World market cocoa price.[a]

$PICCO_t = \alpha_1 CPI_t - \alpha_2 [ERWT_t - (IRWT_t + 0.225 \times \Delta IRWT_t)] - \alpha_3 [STWT_{t-1} - 0.225 \times IRWT_{t-1}] + \alpha_4 PICCO_{t-1} + \alpha_5 DU77$

Parameter	α_1	α_2	α_3	α_4	α_5	R^2
Value	0.85	0.22	0.06	0.71	145.29	0.97
t	(3.1)	(3.6)	(2.0)	(6.5)	(6.4)	

[a] A dummy variable $DU77$ for the year 1977 was introduced to account for the extreme increase in $PICCO$ in that year.

The global structure of the model is as follows. The non-controllable exogenous variables are the commodity price indices, PC, for each country or region, real income, $GNPR$, and population size, POP, for each consuming region, an autonomous import component, $CCRR$, the general commodity price index, CPI, the price index for sugar, PS, and the exchange rates, RE. The instrumental variables are the change, ΔBST, in the buffer stock and the changes, ΔST, in stocks for each country or region. These instrumental variables were set equal to zero in the estimation procedures. The endogenous variables are production,

QR, the producer price index, PFI, and the export price index, PE, for each producing country or region, consumption, CC, and the import price index, PI, for each consuming region, total exports, $ERWT$, total imports, $IRWT$, free stocks, $STWT$, and the world market price index, $PICCO$. Given time paths for the non-controllable exogenous variables and for the instrumental variables the model generates time paths for the endogenous variables from an appropriate set of initial values. The model is linear in the endogenous and instrumental variables. Non-linearities such as the transformation from nominal to real variables or from US dollars to home currency are reflected in the time varying coefficients of an essentially linear model.

In order to be able to apply control algorithms the model is rewritten in state space form. This means that the set of higher order difference equations is rewritten as a set of first order difference equations by stacking lagged endogenous and instrumental variables into a state vector and by solving this set of equations for the state transition. The result is

$$x_{t+1} = A_t x_t + \sum_{i=1}^{13} B_t^i u_t^i + z_t \tag{10}$$

where x is the state vector and u^i the instrumental vector for market participant i, $i = 1, \ldots, 13$, and where the exogenous influences are reflected in the time varying parameters A, B and z. The state vector consists of all the endogenous variables with one lag and the producer price indices, PFI, up to their maximum lag, which adds up to 75 elements. The instrumental vectors have only one element. The objective variable of the buffer stock manager is the world market price. In the game exercises in the next two sections the producing countries or regions have as objective variable their export price index and the consuming regions have as objective variable their import price index. Since these objective variables form a subset of the state variables the vector y of objective variables can be written as

$$y = Cx \tag{11}$$

In the next section control and game algorithms are given for the abstract model, (10)–(11). In the section after these algorithms are applied to the underlying world cocoa model, (1)–(9).

Difference game methodology

The objective of the buffer stock manager is to keep the world market price as close as possible to an *a priori* specified target price path by selling and buying on the world market. Therefore the basic part of the objective functional of the buffer stock manager consists of squared deviations of the world market price path, $PICCO$, from this target price path, $\widehat{PICCO}$. The interventions of the buffer stock manager are restricted by the available buffer stock and/or the available budget. An optimal degree of price stabilization can be found by using as objective functional the weighted sum of squares over a fixed planning horizon

$$\sum_{t=1}^{T} [q(PICCO_t - \widehat{PICCO}_t)^2 + r(\Delta BST_t)^2] \tag{12}$$

A high value for the relative priority q/r will generally lead to a good stabilization result with strong interventions, whereas a low value for q/r will generally lead to a bad stabilization result with minor interventions. Given the restrictions on interventions there will generally be a best stabilization result corresponding with an optimal value for the relative priority q/r.

The objective functionals of the other market participants are formulated in the same way, with the world market price replaced by the export price for the producing countries or regions and by the import price for the consuming regions. These objective functionals reflect the idea that, although producing and consuming countries and regions participate in the buffer stock in order to stabilize prices, there may be additional storage activities in these countries and regions in order to try to get higher export prices or lower import prices. This leads to a strategic interaction between buffer stock manager, producers and consumers, which can be modelled as a difference game. In terms of the state space form, (10)–(11), of the model this difference game consists of the objective functionals

$$J_i(u^1, \ldots, u^{13}) := \sum_{t=1}^{T} [(y_t - \hat{y}_t^i)' Q_t^i (y_t - \hat{y}_t^i) + u_t^{i\prime} R_t^i u_t^i] \quad i = 1, \ldots, 13 \tag{13}$$

and the constraints (10)–(11), where $\hat{y}^i$ are the vectors of target price paths and where the diagonal matrices Q^i are semipositive definite and the scalars R^i are positive. The quadratic form of the objective functionals implies that deviations above and below the target paths are equally punished. This is a suitable type of criterion for stabilization purposes. However, in this game it is not the objective of producers and consumers to stabilize prices, but to get higher export prices or lower import prices. A way out is to set the target path of export (import) prices high (low) enough for the resulting price path to remain below (above) the target price path. The precise choice of the target paths as well as the relative priorities q/r must again be motivated by the desirability and the feasibility of the outcomes (see also the next section).

Suppose the buffer stock manager is labelled as player 1, the producing countries or regions are labelled as players 2, ..., 9 and the consuming regions are labelled as players 10, ..., 13. In case $Q^i = 0$, $i = 2, \ldots, 13$, the producing and consuming countries and regions do not act and an optimal control problem remains for the buffer stock manager.

The behavioural equilibrium concept used to solve the difference game is the non-cooperative Nash concept. It is important to distinguish between the Nash solution with only initial state information and with binding commitments and the Nash solution with current state information and without binding commitments (Basar and Olsder [3], de Zeeuw and van der Ploeg [25]). The first is called the open loop Nash solution and the second is called the feedback Nash or subgame perfect solution. Since it seems more realistic to assume the use of current state information and no binding commitments, the feedback Nash solution is employed here. This behavioural equilibrium is found by solving static Nash games in a dynamic programming framework. The equilibrium strategies are given by de Zeeuw [24]:

$$u_t^i(x) := G_t^i x + h_t^i \quad i = 1, \ldots, 13 \tag{14}$$

where

$$G_t^i := -[R_t^i]^{-1} B_t^{i\prime} K_{t+1}^i [E_{t+1}]^{-1} A_t \tag{15}$$

$$h_t^i := -[R_t^i]^{-1} B_t^{i\prime} \left\{ K_{t+1}^i [E_{t+1}]^{-1} \times \left(z_t - \sum_{j=1}^{13} B_t^j [R_t^j]^{-1} B_t^{j\prime} g_{t+1}^j \right) + g_{t+1}^i \right\} \tag{16}$$

$$E_{t+1} := I + \sum_{j=1}^{13} B_t^j [R_t^j]^{-1} B_t^{j\prime} K_{t+1}^j \tag{17}$$

and where K^i satisfy the coupled backward recursive Riccati-type matrix equations

$$K_t^i = C'Q_t^i C + A_t'[E_{t+1}']^{-1} \times (I + K_{t+1}^i B_t^i [R_t^i]^{-1} B_t^{i\prime}) K_{t+1}^i [E_{t+1}]^{-1} A_t$$

$$K_{T+1}^i = 0 \tag{18}$$

and g^i satisfy the coupled backward recursive tracking equations

$$g_t^i = -C'Q_t^i \hat{y}_t^i + A_t'[E_{t+1}']^{-1} (I + K_{t+1}^i B_t^i [R_t^i]^{-1} B_t^{i\prime}) \times \left\{ K_{t+1}^i [E_{t+1}]^{-1} \left(z_t - \sum_{j=1}^{13} B_t^j [R_t^j]^{-1} B_t^{j\prime} g_{t+1}^j \right) + g_{t+1}^i \right\}$$

$$g_{T+1}^i = 0 \tag{19}$$

The variable x in the strategy representations (14) denotes the state information at time t. In a simulation it is assumed that the players observe the simulated state vector.

Cocoa market as a game

In this section two strategic interventions on the international cocoa market are compared. In the first a buffer stock manager tries to stabilize the world market price by selling and buying on the world market from an available buffer stock. In the second producers and consumers take account of these buffer stock activities and consider intervening for themselves in order to obtain higher export prices or lower import prices. The buffer stock manager realizes this so the three market participants play a Nash game between them. In the first exercise the buffer stock manager employs the optimal control strategy u^1 given by Equations (14)–(19) with $Q^i = 0$, $i = 2, \ldots, 13$. In the second exercise the players employ the set of Nash strategies u^i, $i = 1, \ldots, 13$, also given by Equations (14)–(19). Both control and Nash game algorithms start from the model parameters (A_t, B_t, z_t), the initial state vector x_1, the target paths $\hat{y}^i$ and the relative priorities (Q^i, R^i).

The target path for the world market price should reflect the idea that the buffer stock manager only tries to counter undesirable market forces on the international cocoa market and not the spill over effects from other markets. This target path is therefore constructed as follows (see for other ideas for the construction of target price paths Lee and Blandford [16]; Ghosh, Gilbert and Hughes Hallett [10]; Hughes Hallett [13]). First, the world market price, *PICCO*, is simulated with the cocoa model given above and a trend is determined. Second, the world market price, *PICCO*, is simulated with Equation (9) in which α_2 and α_3 are set equal to zero, which implies market equilibrium, and again a trend is determined. Finally, the deviations from trend in the second simulation are added to the trend found in the first simulation. The resulting price path is taken as the target path for the world market cocoa price. It seems logical to use this target path and Equations (4) and (5) to construct target paths for export and import prices. However, this would typically lead to additional stabilization efforts and not to the sort of conflict that we are attempting to analyse here. In that conflict producers and consumers are trying to get higher export prices and lower import prices respectively and not stable prices. They aim at a better result than they would get by doing nothing. The construction of these target paths is therefore based on the resulting price

Table 7. Optimal control solution.[a]

	ΔBST	Simulated *PICCO*	Target *PICCO*	Controlled *PICCO*
1968	−13.83	64.16	69.29	61.85
1969	−41.67	86.86	78.20	79.86
1970	−29.49	94.21	85.60	90.23
1971	15.01	77.58	89.58	84.65
1972	43.51	63.15	96.28	76.68
1973	19.18	116.70	118.09	122.00
1974	−18.33	187.60	147.23	179.30
1975	−33.56	212.80	156.78	197.30
1976	−29.36	215.20	170.48	200.10
1977	−17.63	369.30	337.47	360.30
1978	4.76	305.60	307.36	310.00
1979	20.46	271.60	297.11	289.30
1980	28.66	225.00	297.46	246.50
$\sum_{68}^{80} =$	−52.29			

$\min_t |BST_t| = BST_{77} = -6.17$

Operating costs (US$): 59 073 000
Inward cash flow (US$): 75 728 000

Stabilization index (simulation): 341.59
Stabilization index (control) : 228.62

[a] The stabilization index is defined as $\Sigma_{t=68}^{80} |PICCO - PICCO|$. The operating costs for the buffer stock manager are defined as

$$\sum_{t=68}^{80} \Delta BST_t \times PICCO_t + (BST_{67} - BST_{80})(PICCO_{80} - [-0.216 \times (BST_{67} - BST_{80})])$$

The first term is the total yearly outward cash flow from selling and buying. The second term represents the costs for restoring the buffer stock at its initial level. The warehouse costs of the buffer stock are not taken into account.

paths from the control experiment. The target paths for export prices are set 10% higher than the result of the control experiment and the target paths for import prices are set 10% lower.

The control experiment is set up as follows. The buffer stock manager is given an initial buffer stock of 100000 metric tons. The relative priority Q^1_{11}/R^1 is determined by experiment. The value of R^1 is arbitrarily set at 10. Starting at 0 the value of Q^1_{11} is gradually increased until the accumulated buffer stock changes just hit the ceiling of 100000 metric tons somewhere in the sampling period, which happens for $Q^1_{11} = 30$. This is the best stabilization result the buffer stock manager can achieve with the available buffer stock. The results are presented in Table 7.

The game experiment is essentially set up in the same way. The values of R^i, $i = 2, \ldots, 13$, are also arbitrarily set at 10. The values of Q^i_{ii}, $i = 2, \ldots, 13$, are also gradually increased starting at 0 until the accumulated interventions on the producers' side and the consumers' side unrealistically exceed a preset value of about 140000 metric tons. From the experiments it is found that an increasing Q^i_{ii}, which must lead to higher export prices and lower import prices respectively, also leads to more income for the producing countries and regions and lower costs for the consuming regions. This implies that prices are a good indicator of revenues and costs so that the experiment was set up realistically in that respect in the first place. It remains to be seen what happens when both producers and consumers try to improve their situation by speculative actions.

The results of the game experiment are presented in three steps. First, there is only a game between buffer stock manager and producing countries and regions in which the consuming regions remain passive. This is called game 1. Second, there is only a game between buffer stock manager and consuming regions in which the producing countries and regions remain passive. This is called game 2. Finally, the game between the three market participants is called game 3. It is found that in the games with consuming regions there is more room for the buffer stock manager to operate in. In these games the value of Q^1_{11} can be increased to 35. In game 1 the preset boundary for the producing countries and regions is hit for $Q^i_{ii} = 6$, $i = 2, \ldots, 9$. In game 2 the preset boundary for the consuming regions is hit for $Q^i_{ii} = 10$, $i = 10, \ldots, 13$. In game 3 the preset boundaries are hit for $Q^i_{ii} = 5$, $i = 2, \ldots, 9$ and $Q^i_{ii} = 9$, $i = 10, \ldots, 13$. It is possible to vary the values of Q^i_{ii} over the different countries and regions and over time. One variation is to relate these values to the size of the trade of each country and region so that the resulting interventions will also be related to the size of the trade. It turns out that the market results remain essentially the same. The reason is that the interventions of the producers as a group and of the consumers as a group remain essentially the same. The results with these values for Q^i_{ii} are presented in Table 8 for game 1, Table 9 for game 2 and Table 10 for game 3.

The first conclusion to be drawn from the figures in Tables 7–10 is that the pattern of the buffer stock interventions is the same in all four experiments. The buffer stock manager starts to sell for three periods, then buys for three periods, then sells again for four or five periods and ends up buying. In total the buffer stock manager is a seller. The producing countries or regions are predominantly withholding in order to lower supply to increase prices and the consuming regions are predominantly using up their stocks in order to lower demand to decrease prices, which is to be expected.

As an indicator of the degree of stabilization the sum of absolute differences between the values of the resulting price path and the corresponding values of the target price path is used. The optimal control

Table 8. Game between buffer stock and producers (game 1).

	ΔBST	$\sum_{i=1}^{8} \Delta ST_i$	$\sum_{i=1}^{4} \Delta ST_i$	Total intervention	*PICCO*
1968	−5.96	−5.77	0.0	−11.73	62.20
1969	−32.02	0.44	0.0	−31.58	81.56
1970	−27.44	8.18	0.0	−19.26	91.84
1971	9.26	10.75	0.0	20.01	84.55
1972	37.67	6.92	0.0	44.59	75.31
1973	17.98	2.81	0.0	20.79	121.10
1974	−16.08	2.92	0.0	−13.16	180.10
1975	−31.57	6.81	0.0	−24.76	199.70
1976	−30.25	15.12	0.0	−15.13	204.30
1977	−22.42	26.82	0.0	4.40	366.40
1978	−1.55	28.24	0.0	26.69	316.00
1979	15.90	25.16	0.0	41.06	293.70
1980	27.68	13.13	0.0	40.81	248.20
$\sum_{68}^{80} =$	−58.80	141.53	0.0	82.73	

$\min_t |BST_t| = BST_{78} = -2.38$

Operating costs (US$): 12 932 000
Inward cash flow (US$): 122 502 000
Benefits producers (US$): 500 007 000
Benefits consumers (US$): −245 125 000

Stabilization index : 245.55

Table 9. Game between buffer stock and consumers (game 2).

	ΔBST	$\sum_{i=1}^{8} \Delta ST_i$	$\sum_{i=1}^{4} \Delta ST_i$	Total intervention	*PICCO*
1968	−13.30	0.0	4.58	−8.72	62.88
1969	−35.52	0.0	−2.70	−38.22	80.17
1970	−24.11	0.0	−9.22	−33.33	88.75
1971	16.99	0.0	−9.65	7.34	82.58
1972	43.98	0.0	−5.13	38.85	76.25
1973	16.78	0.0	−1.49	15.29	122.80
1974	−22.46	0.0	−2.34	−24.80	179.40
1975	−36.41	0.0	−7.08	−43.49	196.10
1976	−28.69	0.0	−16.07	−44.76	196.90
1977	−14.73	0.0	−25.87	−40.60	354.20
1978	9.73	0.0	−28.23	−18.50	302.20
1979	25.77	0.0	−24.83	0.94	282.80
1980	34.35	0.0	−12.02	22.33	245.10
$\sum_{68}^{80} =$	−27.62	0.0	−140.05	−167.67	

$\min_t |BST_t| = BST_{77} = 2.53$

Operating costs (US$): 53 749 000
Inward cash flow (US$): 23 950 000
Benefits producers (US$): −542 746 000
Benefits consumers (US$): 212 358 000

Stabilization index : 229.74

Table 10. Game between buffer stock, producers and consumers (game 3).

	ΔBST	$\sum_{i=1}^{8} \Delta ST_i$	$\sum_{i=1}^{4} \Delta ST_i$	Total intervention	*PICCO*
1968	−8.29	−5.65	4.86	−9.08	62.83
1969	−30.71	0.94	−3.06	−32.83	81.05
1970	−24.26	8.73	−10.07	−25.60	90.11
1971	12.48	10.50	−10.14	12.84	83.18
1972	40.16	5.46	−4.71	40.91	75.69
1973	16.66	1.06	−0.48	17.24	122.10
1974	−20.25	1.82	−1.52	−19.95	179.70
1975	−34.84	6.41	−7.00	−35.43	197.70
1976	−29.86	14.95	−16.93	−31.84	200.10
1977	−19.41	26.59	−27.54	−20.36	359.40
1978	3.57	28.14	−30.22	1.49	308.10
1979	20.98	24.31	−26.17	19.12	287.60
1980	33.01	11.80	−12.35	32.46	247.10
$\sum_{68}^{80} =$	−40.76	135.06	−145.31	−51.02	

$\min_t |BST_t| = BST_{77} = 1.68$

Operating costs (US$): 32 499 000
Inward cash flow (US$): 72 712 000
Benefits producers (US$): −61 614 000
Benefits consumers (US$): 21 121 000

Stabilization index: 230.37

solution leads to a good stabilization result. This result is somewhat better than for the game solutions. However, the stabilization indices for the games with consumers are almost as good as for the optimal control solution, whereas the stabilization index for the game with only producers is quite a bit worse. This means that the destabilizing effect is mainly due to storage activities in the producing countries and regions.

Net sales from the buffer stock are the lowest in the game with only consumers and the highest in the game with only producers. However, this does not mean that the buffer stock manager is less active in game 2. On the contrary, the sum of interventions in absolute terms is the highest in game 2 and the lowest in game 1. What this does imply is that the costs of replenishing the buffer stock up to the initial level of 100 000 metric tons will be lower. These costs are calculated by multiplying the required quantity by a simulated world market price. In this simulation it is assumed that every market participant has to restore its initial endowment, which determines fictitious supply and demand, and that there are enough buyers or sellers.

In order to get an indicator for the costs of operating the buffer stock the net inward cash flow into the buffer stock has to be subtracted from these replenishment costs. The costs of operating the buffer stock are the lowest for the game with producers only (game 1). The interventions of the producers induce an upward pressure on the world market price, which leads to a very high net inward cash flow into the buffer stock. These revenues outweigh the high replenishment costs for this game. The costs of operating the buffer stock are also very low for the game with producers and consumers (game 3). The interventions of producers and consumers almost cancel out so that the world market price path changes only slightly as compared to the price path in the optimal control solution. Therefore the net inward cash flow into the buffer stock is almost the same. However, the replenishment costs are much lower. The costs of operating the buffer stock for the game with consumers only (game 2) are higher than for the other two games but still lower than for the optimal control solution. The interventions of consumers induce a downward pressure on the world market price, which leads to a low net inward cash flow into the buffer stock. However, the replenishment costs are much lower, since a large buffer stock remains at the end, and this outweighs the lower revenues.

The results of game 1 and game 2 show that producers and consumers actually benefit from their actions. The pursuit of higher export prices and lower import prices leads to higher revenues and lower costs respectively. The group that remains passive has a loss. The differences between the gains of the one group and the losses of the other are due to the way in which the market is modelled when the market participants restore their initial endowments. The differences are a gain or a loss of fictitious traders. The results of game 3 show that when producers and consumers are both active the producers are worse off than in the optimal control solution. This is because the attempts of both groups to improve their situation approximately cancel out so that withholding and dumping implies a loss. On the other hand consumers are better off because they restore their used stocks at a favourable price. The values are, however, rather small.

These budget considerations are important in putting the results in the right perspective. Although the general conclusion is that buffer stock stabilization activities are less successful when producing and consuming countries and regions also employ storage activities for their own sake, this conclusion is weakened by the fact that the operating costs of the buffer stock are much lower. Furthermore, the producers have lower revenues and the consumers have lower costs. A topic of further research will be to make an overall cost and benefit analysis and to see if the results are robust for reasonable variations in the target paths and the relative priorities. Finally, the issue of coordination through the buffer stock and conflict on the market afterwards could be analysed further with other non-cooperative and cooperative game theoretic solution concepts.

Conclusion

This paper tries to answer the question of what happens if agents in producing and consuming countries are still strategically active on the international cocoa market, although countries coordinate their stabilizing efforts through a buffer stock manager. An empirical model for the world cocoa market is constructed and the optimal control solution for the buffer stock manager is compared with feedback Nash or subgame perfect game equilibria between buffer stock manager, producers and consumers. The conclusion is that the stabilizing efforts are partly offset by the strategic activities of the other market participants. However, the costs of operating the buffer stock decrease and some other market participants are better off. A further treatment of the trade off between the stabilization result, on the one hand, and costs and revenues, on the other hand, and the study of other game equilibria are left for further research.

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Appendix 1

List of symbols

BST Buffer stock (1000 metric tons)

CC Consumption of cocoa (1000 metric tons), calculated by adding grindings and imports in bean equivalents of the various consuming areas. *CCRR* is obtained by subtracting the consumption in the other four areas from world grindings. Data taken from FAO *Cocoa Statistics* [6] and Gill and Duffus *Cocoa Market Reports* [11]

CPI Commodity price index (1980 = 100): data from *International Financial Statistics* [15]

ERWT World supply of cocoa beans: $\sum_{j=1}^{n} QR_j - \Delta ST_j$

IRWT World demand for cocoa beans: $\sum_{j=1}^{4} CC_j - \Delta ST_j$

GNPR Gross national product in purchasers' values in billions of US$ (at exchange rates and price levels of 1975). Data available for the period 1960–82 for Western Europe and North America. For the rest of the developed world data are from Japan, Australia and New Zealand [18]. For Eastern Europe and the USSR the data are taken from OECD [19] (available as an index (1975 = 100) for the period 1960–80)

HY Percentage of total area planted with cocoa that is planted with hybrid varieties. This is defined only for Ivory Coast and Brazil [5]

PC Index of consumption prices (1975 = 100). For the consuming regions this index is calculated by dividing nominal private consumption per region by real private consumption per region at 1975 prices and exchange rates from the OECD *National Accounts* for the period 1960–82 [18]. For Eastern Europe and the USSR no data are available. For the producing countries data are available per country for the period 1953–84 (except for Cameroon and Ivory Coast) from the *International Financial Statistics* [15]. For Cameroon and Ivory Coast data for the missing years (1953–62 and 1953–60 respectively) were constructed by regressing the index for each country on the index for total Africa and predicting the missing observations. For the three remaining areas data are constructed as follows: the rest of Africa, the consumer index for total Africa, period 1953–84; Asia and Oceania, the consumer price index for total Asia, period 1953–84; the rest of South America, the average of the consumer price indices (weighted with production of beans) of Ecuador, Mexico and the Dominican Republic, period 1956–84; all taken from OECD *National Accounts* [18] and *International Financial Statistics* [15]

PE Unit value of exports (US dollar cents per kilo). Nominal exports are divided by real exports in 1975 prices; data from FAO *Cocoa Statistics* [6] and FAO *Trade Yearbook* [7]

PFI Index of producer prices in home currency (1975 = 100). Producer prices in home currency are available for countries. For the rest of Africa a weighted average of producer prices in US dollar cents of the four other countries is used. Producer prices for the rest of South America and Asia and Oceania are set equal to export prices. Data are available for: Cameroon (1958–82), Ghana (1953–82), Ivory Coast (1957–82), Nigeria (1953–82) and Brazil (1966–82) from Gill and Duffus *Cocoa Market Reports* [11]

PI Unit value of imports (US dollar cents per kilo). Nominal imports are divided by real imports in 1975 prices, data from FAO *Cocoa Statistics* [6] and FAO *Trade Yearbook* [7] (except for Eastern Europe and the USSR, 1965–82)

PICCO Annual average of daily prices of cocoa beans (US dollar cents per kilo) from [6] and [8]

POP Population in millions, from IMF [15] and OECD [19]

PS Price of sugar on the world market (US dollar cents per kilo) (World Bank [23])

QR	Production of cocoa beans (1000 metric tons) per annum (1 October – 30 September); FAO *Cocoa Statistics* [6] and ICCO *Quarterly Bulletin of Cocoa Statistics* [14]
RE	Rate of exchange in units per US dollar (for regions *RE* equals 1); *International Financial Statistics* [15]
ST	Strategic stocks held by producing and consuming countries
STWT	Free world stocks of cocoa beans (1 000 metric tons) calculated starting from 1960 as reported by Gill and Duffus [11]

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